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155-mm Howitzer Malfunction Investigation: A Laboratory Study of the Igniter Train Operation

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Abstract

On 20 December 1974, two hangfires occurred in a developmental 155-mm howitzer at Aberdeen Proving Ground (APG), MD. The second hangfire was accompanied by a rupturing of the howitzer breech. As a result of this, a laboratory study was initiated to uncover possible causes leading to the malfunction. The study involved testing of various components of the igniter train singly and in various combinations under a variety of environmental conditions.

The sequence of events leading to the hangfires was as follows: the primer ignited the base pad, which did not ignite the propellant nor the black powder containing central core "snake." The NC tube ignited to a fizz burn after a period of seconds and eventually ignited the propellant that caused the hangfires. The ignition occurred in a localized region near the breech, leading to the pressure waves of extreme magnitude. Subsequent high pressures that ruptured the breech may have come about because of cold propellant grain fracture due to pressure wave induced acceleration against the projectile. The difference between the apparently reliable operation of the XM123E2 interim propellant charge and the charge (XM230E1) used in the hangfires and in this study was due to the change in igniter train cloths. This was confirmed by post-firing analysis of cloth residues, visual differences in cloth density, and full-scale blowout cannon results.

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1. Introduction

The objective of this study was to analyze the operation of the igniter train assembly of the Zone 8 155-mm XM203E1 propelling charge (see Figure 1) for the XM198 howitzer. This work was motivated by two malfunctions that occurred during the cold-temperature −54° C (−65° F) phase of the Ammunition Safety Certification Tests [1] conducted at Aberdeen Proving Ground (APG) on 20 December 1974. The results of the two malfunctions can be summarized as follows.

- Round 142: Hangfire,10 s (minimum, not measured); muzzle velocity, 857 m/s (2,812 ft/s) and 61 m/s (200 ft/s) higher than a normal cold round; mean chamber pressure, 379 MPa (55,000 psi) and ~110 MPa (16,000 psi) higher than a normal cold round.

- Round 143: Hangfire, 5.8 s (measured); erratic pressure vs. time trace with a chamber pressure in excess of 793 MPa (115,000 psi) causing a breechblow and extensive damage to the XM199E5 cannon tube. The pressure vs. time history for this round is shown in Figure 2.

In the normal functioning of the igniter system, Figure 1(b), the firing pin initiates the M82 primer; the output of the primer ignites the base pad (containing black powder) located at the rear of the charge; the output of the base pad, in turn, ignites the central core tube of black powder (snake) located coaxially with the charge inside of a nitrocellulose (NC) tube; and the output of central core tube results in radial ignition of the propellant bed.

To uncover the origin of these malfunctions, a program was initiated to study the functioning of all the igniter components of the XM203El charge. An analysis was carried out of the makeup of the igniter train, the past history of test rounds fired under another test program [2, 3], subsequent charge modification, and the data and observations of these malfunctions. In the light of this analysis, certain assumptions were initially made concerning the malfunction. Previous investigators [2] have shown that base pad ignition, without ignition of the NC tube or black powder snake, will cause rapid localized ignition of the propellant. Such a configuration can lead to undesirable

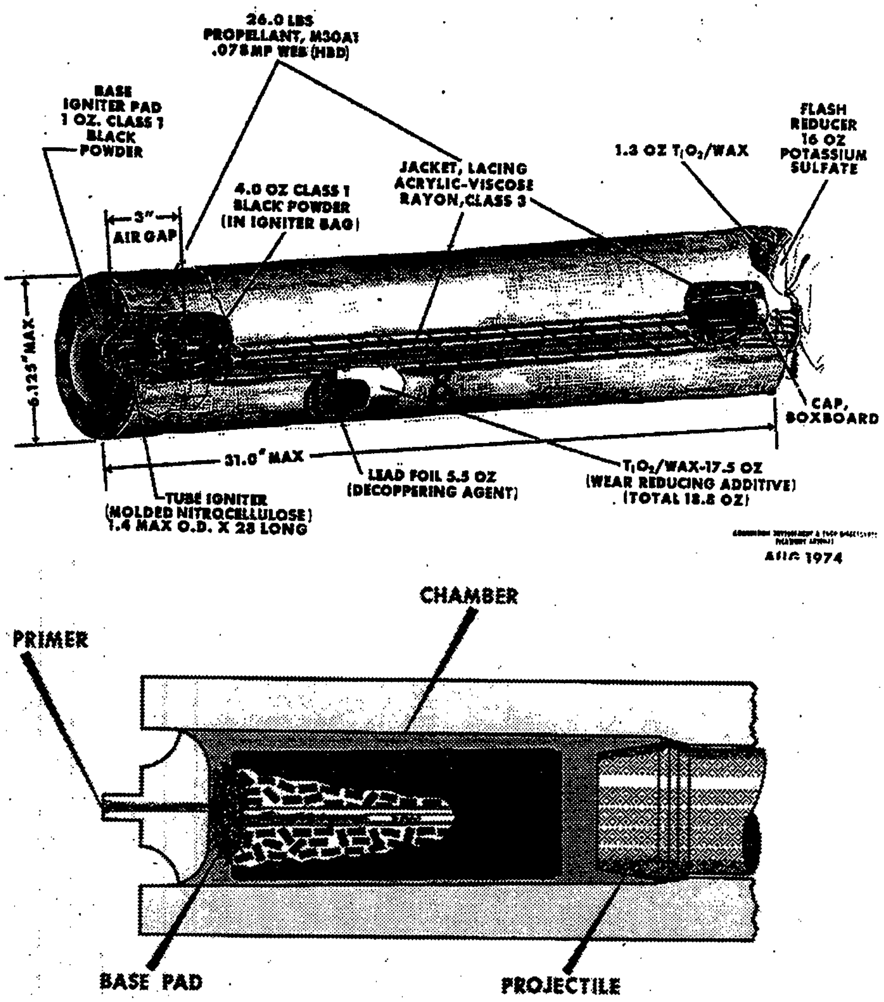


Figure 1. Illustrations of (a) Charge-Propelling 155-mm XM203E1 and (b) Igniter Functioning in Gun Chamber.

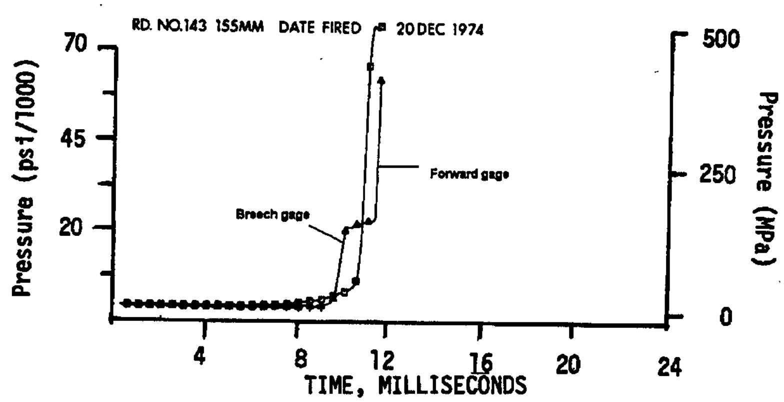


Figure 2. Pressure-Time Trace of Breechblow Round Fired at APG With XM203E1 Charge Conditioned to −54° C in XM198 Howitzer.

pressure waves during the ballistic cycle, but hangfires were never encountered. Consequently, it was assumed that, in order to show the cause of the hangfires, some configuration or set of circumstances must be found, which would demonstrate that it was possible for the M82 primer to function but, at the same time, fail to immediately ignite any component of the igniter train.

The following questions were raised concerning factors that could have possibly contributed to the malfunction of the igniter train.

(1) In going from the XM123E2 interim charge to the XM203E1 charge, changes were made in the base pad material, viz., from viscose-rayon resin-impregnated Class 3, to polyester viscose-rayon Class 6. Did the change in this material, coupled with the low-temperature soak at −54° C (−65° F), cause a significant change in the ignition characteristics of the base pad?

(2) Is it possible to locally ignite the M30A1 propellant directly by the M82 primer and, thus, completely bypass the igniter train?

(3) Is it possible to ignite the ignition train or propellant with an "inverted charge" configuration, that is, with the charge loaded backward?

(4) Was the M82 primer output altered in some way so as to be ineffective in igniting the black powder?

(5) Was the black powder used in the XM203El charge (Lot CIL 7–3) ballistically defective?

(6) What component of the system is capable of yielding ignition delays from 5–10 s?

(7) Is it possible to develop hangfires with a missing or partially empty base pad from the igniter train?

(8) Does moisture significantly affect the performance of the base pad?

(9) In examining the black powder snakes from various charges, it was observed that up to 8 cm (~3 in) of empty cloth could be produced by shaking the black powder to one end of the tube. This could result in a 15 cm (6 in) standoff between the base pad and the black powder in the snake. Could such a standoff cause hangfires in the igniter train?

(10) The charges were temperature-conditioned in an environmental chamber that used liquid CO_2. Could a malfunction in the cooling system result in charges that are conditioned at dry-ice temperatures $-78°$ C ($-109°$ F)? If so, could this low temperature cause a malfunction in the igniter train?

(11) The igniter system was designed with a 7.5-cm (3 in) gap between the black powder base pad and center core snake (Figure 1). Does the confinement of the charge within the chamber have an effect on the ignition of the snake by the base pad?

(12) Due to the differences in diameters of the charge and chamber and the presence of the "Swiss notch,"* it is possible for the center of the charge to be ~1.5 cm (0.6 in) off axis from the primer "spit hole" located in the breech. In addition, charge design specifications allow for 1.9 cm (0.75 in) of misalignment of the NC tube with respect to the charge. Is it possible for misalignment to cause a hangfire in the igniter system?

(13) Is it possible to determine from an examination of the pressure-time from Rounds 142 and 143 whether or not any or all of the igniter components functioned normally? What pressures should be expected from the igniter train?

(14) As mentioned earlier, the hypothesis up to now has been that one or more of the igniter elements failed to function. Previous experiments with base pad ignition have shown that

* Swiss notch: an indentation in the rear bottom of the gun chamber. Used to retain the propelling charge when the howitzer tube is in an elevated position.

hangfires do not occur with a functioning base pad [2]. This hypothesis should be reexamined, considering that the present malfunction occurred at $-54°$ C ($-65°$ F) and that a new and more durable cloth was used for the base pad (as well as a different primer). The question that should be asked is, "Will a fully loaded and operating base pad ignite the M30A1 propellant?"

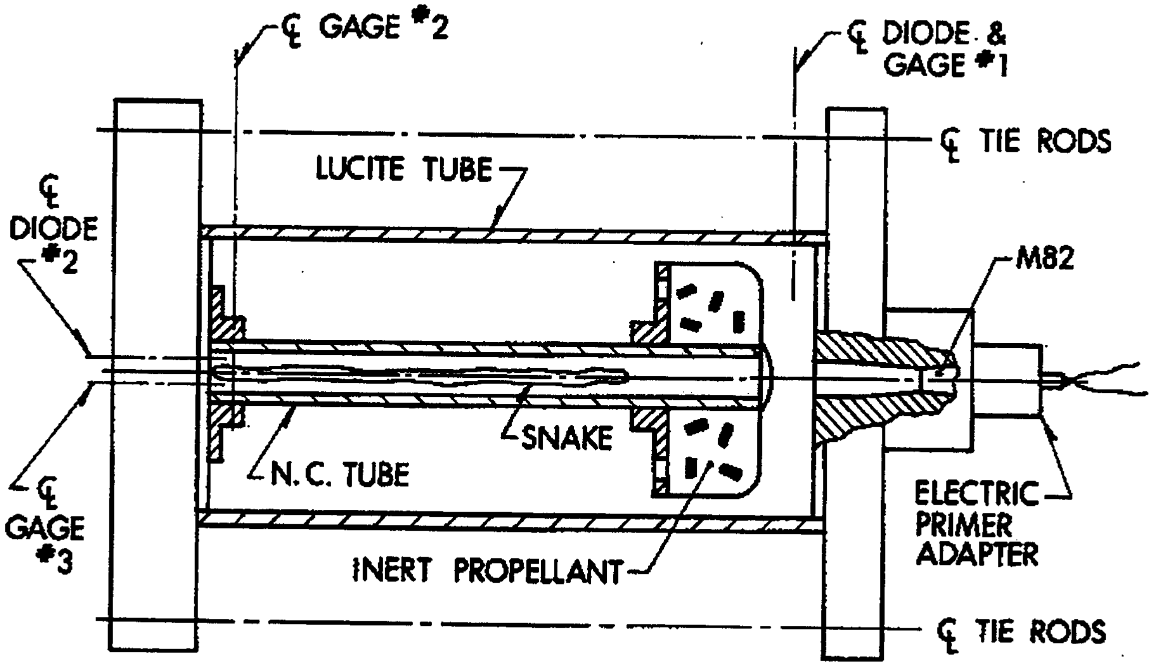
(15) Is it possible that the black powder in the base pad sifted into an area such that the product of the M82 primer penetrated an empty portion of the base pad and, consequently, did not ignite the base pad?

The succeeding sections consist of the following information: section 2, details of the experimental setup; section 3, details of the experimental results as they address each question posed; section 4, the answer to each question arrived at from the results; section 5, a description of the causes of the malfunction and some general remarks about the functioning of the igniter system. White et al. [4, 5] and Shulman, Lenchitz, and Bottei [6, 7] contain other information from this investigation—in particular, the work that was carried out at Picatinny Arsenal.

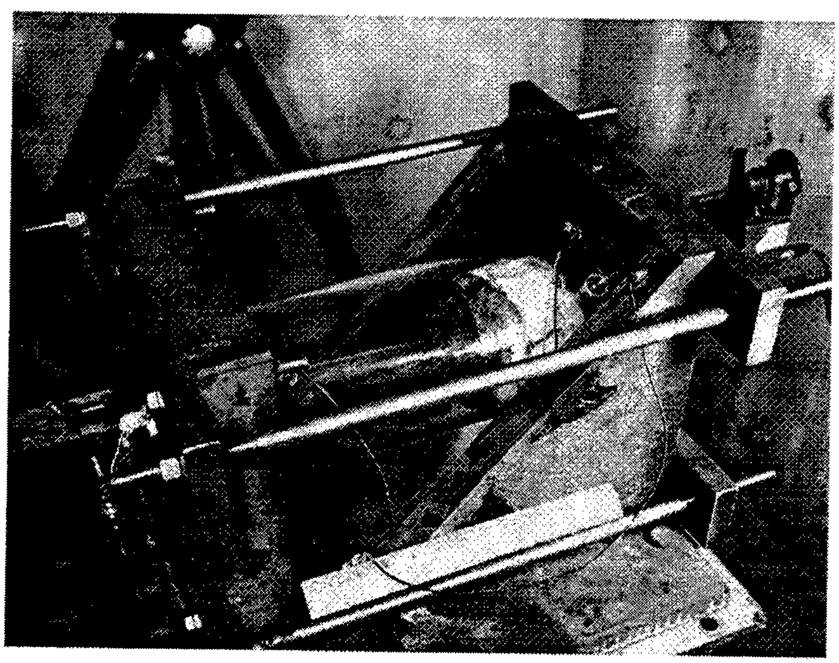
2. Experimental

The actual igniter train used in the XM203E1 charge consisted of a base pad containing 28 g (1 oz) of Class 1 black powder; an igniter tube of molded NC, 71-cm (27.9 in) length × 3.56-cm (1.4 in) outside diameter (OD); and a 63.5-cm-long (25 in) black powder snake located inside the igniter tube, 7.5 cm (3 in) from the base pad containing 113 g (4 oz) of Class 1 black powder (Figure 1). For convenience and speed of getting the study started, a laboratory simulator was used that would only accommodate an igniter train shorter than the actual igniter system was chosen. A diagram of the apparatus is shown in Figure 3(a). A picture of the setup is shown in Figure 3(b).

The chamber consisted of a 35-cm (14 in) length of acrylic tube with a 15-cm (6 in) inside diameter (ID) and a 0.64-cm (1/4 in) wall thickness with steel end plates. One end plate held the primer firing mechanism, a standard spindle from an XM199 cannon. The ignition train simulator



(a)



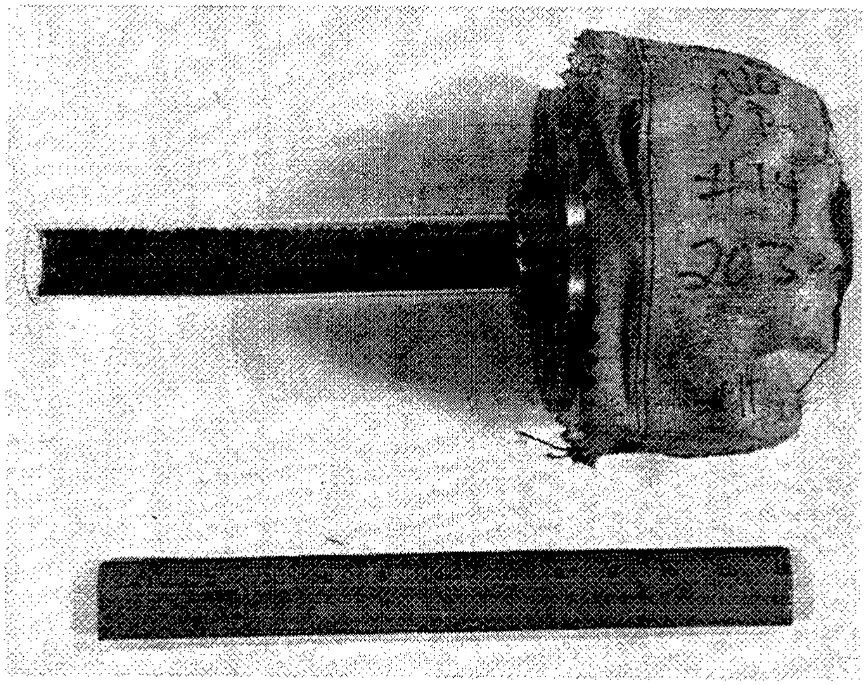
(b)

Figure 3. Laboratory Simulator for Ignition Train Studies: (a) Schematic and (b) Photograph.

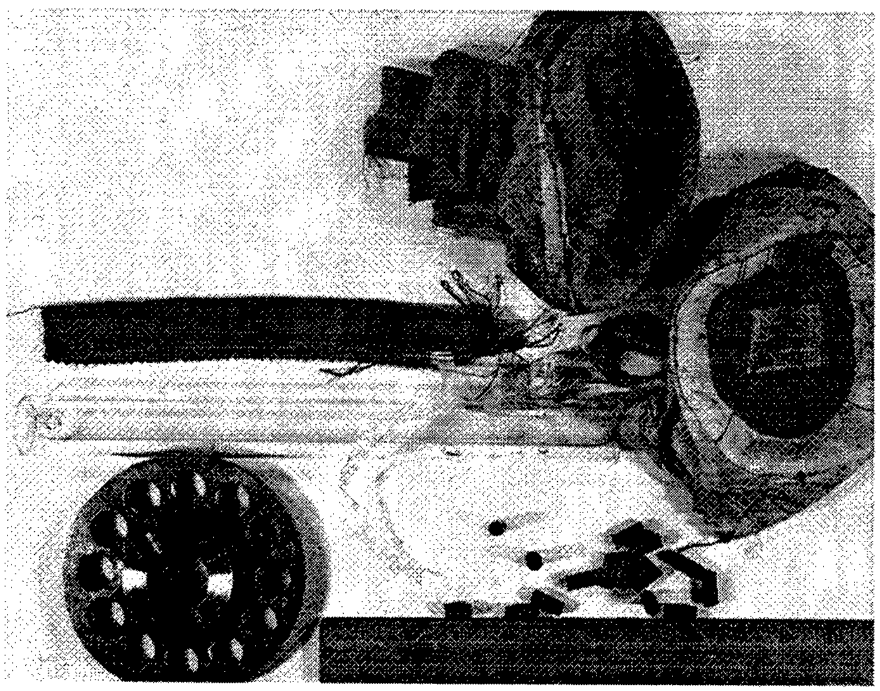
consisted of a central core plastic tube with a 3.2-cm (1 1/4 in) OD mounted on one end plate coaxially with the 35-cm acrylic tube. The charge base pad and propellant bag were mounted on the end of this tube (Figure 4) in a manner similar to that in the actual charge (Figure 1). The propellant bag was filled with ~500 g (17.6 oz) of inert propellant so as to leave 4,750 cm [3] of free space in the chamber. A backing plate was placed against the rear of the inert propellant bag and secured to the central tube with set screws. Except as otherwise specified, a 2.5-cm (1 in) standoff was maintained between the end of the primer spit hole and the surface of the base pad. It was possible to simulate a variety of configurations with this setup. A 23.5-cm-long (9 1/4 in) black powder snake with 50 g (1.76 oz) of black powder could be inserted and tied in the central 3.2-cm tube; the base pad could be filled with 28 g (1 oz) of black powder or propellant, or it could be left empty. The NC tube could be substituted for the plastic tube. The entire ignition train simulator could be conditioned at low temperature (−54° C) and then loaded and fired in less than 3 minutes.

An exploded view of a typical charge can be seen in Figure 4(b), with a few representative grains of inert propellant. In this case, both the snake and the base pad are empty. An assembled view of this charge can be seen in Figure 4(a). It should be mentioned here that, for Runs 1–23, the center of the charge was carefully aligned with the primer output spit hole. Later runs were directed at testing the concept that misalignment of the charge could contribute to the hangfires.

Instrumentation (see Figure 3[a]) consisted of three pressure gauges (Kistler 601B): Gauge 1 (mounted in chamber wall) monitored the pressure in the standoff region, Gauge 2 (mounted in chamber wall) measured the pressure in the rear of the chamber, and Gauge 3 (mounted in the end plate) measured the pressure at the base of the central core plastic tube or NC tube. In addition, two light-detecting diodes (Texas Instrument Type IN2175 photodiode tube) were used: Diode 1 monitored the light output in the standoff region and Diode 2 monitored the light output inside of the central core plastic tube. Television with video tape was used to record the entire event. In some cases, high-speed photographic records were taken. The M82 primers (LOT LS-159-54) were initiated by a plunger driven by electrically initiated Winchester (M52A3Bl) primers. Time zero was taken to be the time of application of voltage to the Winchester primer. Igniter trains were from XM123E2 interim charges (LOT IND-E-124-74) and from XM203E1 charges (LOT IND-E-148-74).



(a)



(b)

Figure 4. Fully Assembled Igniter Simulator Charge Views: (a) Normal and (b) Disassembled.

A few experimental runs were made with a full-length charge with the M30Al replaced with inert propellant. For these runs, a propelling charge storage container was used as a chamber (16.5-cm [6.5 in] ID and cut to a length of 80 cm [31 1/2 in]). One gauge and a diode were mounted in the standoff region, and another gauge was mounted at the midpoint of the tube.

3. Test Results

This section deals with the details of the test configurations and the results. The particular question that was to be addressed is given and the tests germane to that question are described. Pressure-time and light-intensity-time (diode output) curves are given where appropriate. Post-firing pictures of the base pad, etc., are also given for some runs. Table 1 summarizes all test results where data were available.

For easier reading, from here on in this report, the XM123E2 interim charge will be referred to simply as 123, and the XM203E1 charge will be referred to as 203.

3.1 Question 1: Runs 3–8. Is there a difference in the base pad performance between the 203 and the 123 due to the change in material?

3.1.1 Run 3. The pressure records were lost on this run due to lack of thermal protection for the transducers. Television results and diode recordings indicate an ignition delay of well under 1 s.

3.1.2 Run 4. Ignition delays and pressures are listed in Table 1. The M82 primer pulse was a distinct event and can be separated from the operation of the base pad. Note that Gauge 3, located directly in line with the primer, sees a much larger pressure than Gauge 1 or 2. Figure 5 is a pressure-time curve for Gauge 3. The pressure pulse from the M82 is clearly seen at about 3 ms. The Diode 1 signal is shown in Figure 6. The M82 light output is observed at around 3 ms, followed by the base pad light output, which saturates the system. The pressures measured in these

Table 1. Test Shot Summary of XM203E1 Ignition Train Study

Question	Run	Cham. (cm)	Charge Type	Base Pad (g)	Center Core Type	Snake (g)	Temp. (°C)	Prop.[a]	D1 t_1 (ms)	D2 t_2 (ms)	Gauge 1 P_{max} (MPa)	Gauge 1 Delay (ms)	Gauge 2 P_{max} (MPa)	Gauge 2 Delay (ms)	Gauge 3 P_{max} (MPa)	Gauge 3 Delay (ms)	M82 Gauge 3 P_{max} (MPa)	M82 Gauge 3 Delay (ms)	Remarks
1	3	35	123	28	Plex	0	-54	None	—	20	—	—	—	—	—	—	—	—	Ignition delay normal
1	4	35	203	28	Plex	0	-54	None	9	0	1.30	54	0.85	54	1.30	54	1.15	2	Ignition delay normal
1	5	35	203	28	Plex	0	-54	None	8	—	1.00	50	1.10	48	1.10	49	1.05	2	Ignition delay normal
1	6	35	203	28	Plex	0	+12	None	—	11	1.20	35	1.20	35	1.20	32	1.33	2	Ignition delay normal
1	7	35	123	28	Plex	0	+13	None	5	—	1.10	32	1.15	32	1.15	30	1.35	5	Ignition delay normal
1	8	35	123	28	Plex	0	-54	None	3	—	1.05	54	1.05	50	1.06	49	1.30	3	Ignition delay normal
2	9	35	203	0	Plex	0	-54	9	—	—	—	—	—	—	—	—	1.60	2	No ignition propellant
2	10	35	203	0	Plex	0	-54	10	—	—	—	—	—	—	—	—	0.20	2	No ignition propellant
2	11	35	203	0	Plex	0	-54	19	—	—	—	—	—	—	—	—	0.20	3	No ignition propellant
2	12	35	203	0	Plex	0	-54	14	1	—	—	—	—	—	—	—	0.15	3	No ignition propellant
2	17	35	203	0	Plex	0	+13	9	2	—	—	—	—	—	—	—	0.85	2	No ignition propellant
3	13	35	203	0	Plex	0	+13	14	1	—	—	—	—	—	—	—	<0.05	2	No ignition propellant/flash reducer
3	20	35	Prop. Bag	None	NC	0	+13	None	1	—	—	—	—	—	—	—	—	—	No ignition NC tube/flash reducer
6	14	35	123	0	NC	0	-54	None	Television Record Only										Ignition delay 5–10 s
6	19	35	203	0	NC	0	-54	9	—	—	—	—	—	—	—	—	1.25	3	1-cm Standoff/ignition delay 5–10 s
6	21	35	203	0	NC	0	-54	10	—	—	—	—	—	—	—	—	0.10	3	5-cm Standoff/no ignition NC tube
7, 12	15	35	203	0	Plex	50	-54	None	—	40	—	—	—	—	1.40	60[b]	0.85	2	Ignition delay normal
7, 12	26	35	203	0	NC	50	-54	None	1	—	1.40	65[b]	1.40	65[b]	1.40	65[b]	>1.40	3	Ignition delay normal/0.8-cm misalignment, 13-cm inert propellant
7, 12	27	35	203	0	NC	50	-54	None	—	—	1.40	101[b]	1.40	100[b]	1.40	100[b]	0.07	3	Ignition delay normal/2-cm misalignment, no inert propellant
7, 12	28	35	203	0	NC	50	-54	None	—	110	—	—	—	—	1.40	120[b]	0.14	3	Ignition delay normal/2-cm misalignment, no inert propellant
7, 12	29	35	203	0	NC	50	-54	None	—	120	—	—	—	—	1.40	150[b]	0.20	6	Ignition delay normal/2-cm misalignment, no inert propellant
7, 12	43	35	203	0	NC	34	-54	None	—	—	—	—	—	—	—	—	0.07	3	5–10-s Delay of NC ignition/no ignition of snake/1.3-cm misaligned, flash reducer

[a] Number of propellant grains.
[b] Chamber ruptured before P_{max}, hence delay is the time to reach 1.4 MPa.

Table 1. Test Shot Summary of XM203E1 Ignition Train Study (continued)

Question	Run	Cham. (cm)	Charge Type	Base Pad (g)	Center Core Type	Snake (g)	Temp (°C)	Prop.[a]	D1 t_1 (ms)	D2 t_2 (ms)	Gauge 1 P_{max} (MPa)	Gauge 1 Delay (ms)	Gauge 2 P_{max} (MPa)	Gauge 2 Delay (ms)	Gauge 3 P_{max} (MPa)	Gauge 3 Delay (ms)	M82 Gauge 3 P_{max} (MPa)	M82 Gauge 3 Delay (ms)	Remarks
7, 12	44	35	203	0	NC	34	-54	None	—	—	—	—	—	—	—	—	0.15	2	1.2-cm Misalignment/no ignition, flash reducer
8	16	35	203	28	Plex	0	-54	None	8	—	1.07	55	—	—	—	—	0.07	2	Moisture test/ignition delay normal
9	18	35	203	0	Plex	34	-54	None	Television Record Only										15-cm snake standoff/ignition delay normal
10	22	35	203	28	Plex	0	-78	None	5	—	1.10	40	1.05	40	1.10	39	1.05	3	Dry-ice test/ignition delay normal
11	24	None	203	28	NC	112	+15	None	Television Record Only										No inert propellant/base pad ignition normal, snake ignition after 15 s
11	25	None	203	28	NC	112	+15	None	Television Record Only										No inert propellant/base pad ignition normal, snake ignition after 22 s
13	30	77	203	28	NC	112	+15	None	—	145	>0.83	160	>0.79	160	<0.79	160	—	—	Full-length confined charge, 10-kg inert propellant, 1.3-cm misalignment
Base Pad Function Only											0.34	70	0.34	60	0.34	60	—	—	
13	31	77	203	28	NC	112	+15	None	—	—	1.72	165	1.65	175	2.17	165	—	—	Full-length confined charge, 10-kg inert propellant, 1.3 cm misalignment
Base Pad Function Only											0.34	60	0.34	60	0.34	60	—	—	
13	32	77	123	28	NC	112	+15	None	—	—	2.20	160	2.07	160	1.69	160	—	—	Full-length confined charge, 10-kg inert propellant, 1.3 cm misalignment
Base Pad Function Only											0.34	60	0.34	60	0.34	60	—	—	
13	23	77	203	0	NC	112	+15	None	—	—	>1.44	140	>1.31	135	>1.48	139	0.12	4	Full-length confined charge, flash reducer and end cap removed, 10-kg inert propellant
14	33	35	203	28	Al[c]	0	-54	15	8	—	—	—	—	—	0.97	50	0.90	3	Ignition base pad normal, 1.2-cm misalignment/ignition propellant 12-s delay, 1.3-cm inert propellant grains were used, long ignition delay

[a] Number of propellant grains.
[c] Aluminum tube with 2.5-cm section of NC tube attached at base pad end

Table 1. Test Shot Summary of XM203E1 Ignition Train Study (continued)

Question	Run	Cham. (cm)	Charge Type	Base Pad (g)	Center Core Type	Snake (g)	Temp (°C)	Prop.[a]	D1 t_1 (ms)	D2 t_2 (ms)	Gauge 1		Gauge 2		Gauge 3		M82 Gauge 3		Remarks
											P_{max} (MPa)	Delay (ms)	P_{max} (MPa)	Delay (ms)	P_{max} (MPa)	Delay (ms)	P_{max} (MPa)	Delay (ms)	
14	34	35	203	28	Al	0	-54	30	—	—	—	—	—	—	1.00	50	0.62	2	Ignition base pad normal, 1.2-cm misalignment/ignition propellant 10-s delay, 1.3-cm inert propellant grains were used, long ignition delay
14	35	35	203	28	Al	0	-54	30	7	—	—	—	—	—	0.86	50	0.1	5	Ignition base pad normal, 1.2-cm misalignment/no ignition propellant, 1.3-cm inert propellant
14	36	35	203	28	Al	0	-54	30	5	—	—	—	—	—	0.69	40	0.17	5	Same as 35
14	37	35	123	28	Al	0	-54	15	5	—	—	—	—	—	0.55	60	0.07	4	Same as 35
14	38	35	123	28	Al	0	+16	15	4	—	—	—	—	—	0.76	32	1.20	1	Same as 35
14	39	35	203	28	Al	0	-54	15	10	—	—	—	—	—	1.40	35	1.30	2	Ignition base pad normal, 1.2-cm misalignment/ignition propellant, 4 s
14	40	35	203	28	Al	0	-54	16	7	—	0.70	40	—	—	0.76	40	0.45	3	Ignition base pad normal, 1.2-cm misalignment/no ignition propellant
15	41	35	203	28	Al	0	-54	None	20	—	0.72	70	—	—	0.76	70	0.1	2	Ignition delay normal, 1.2-cm misalignment, sifted base pad
15	42	35	203	28	Al	0	-54	None	8	8	0.72	40	—	—	0.75	42	1.79	2	Same as 41

[a] Number of propellant grains.

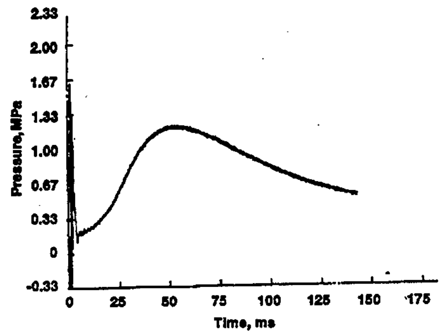


Figure 5. Pressure vs. Time for Run 4, Gauge 3. The 203 Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of −54° C.

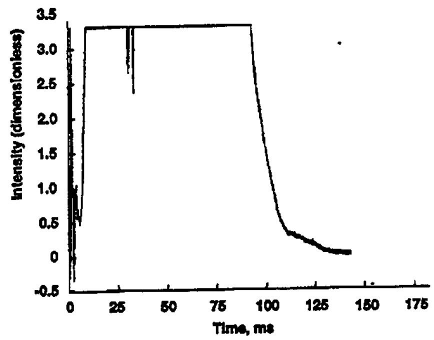


Figure 6. Intensity vs. Time of Diode 1, Run 4.

experiments are lower than those that would be calculated if the apparatus was a closed bomb. This is due to considerable heat loss to the inert propellant bed.

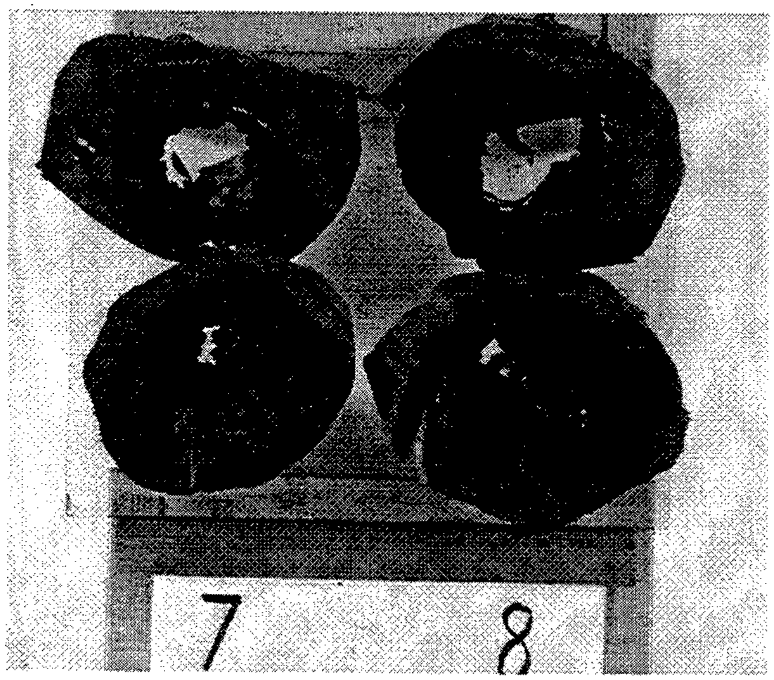
3.1.3 Run 5. Results of Run 5 are much the same as Run 4, which was made under conditions very much like Run 4.

3.1.4 Run 6. Runs 4 (−54° C) and 6 (+12° C) post-firing photos are shown in Figure 7(a). It is seen that there are no significant differences between the low-temperature and ambient firings. Results in Table 1 indicate that the time to peak pressure is slightly longer for the cold runs (54 ms) than for the ambient runs (35 ms). However, no events with delays in the range of seconds were observed. Pressure-time traces are shown in Figures 8 (Gauge 1) and 9 (Gauge 3).

3.1.5 Run 7. Results from Table 1 indicate that pressures and delays are not significantly different from Run 6, which used the 203 material at T = 13° C. Pressure-time traces and Diode 1 output are shown in Figures 10, 11, and 12. The diode (Figure 12) clearly shows the ignition of the M82 followed by ignition of the base pad.

3.1.6 Run 8. Results were very similar to that of Run 5, which used the 203 material at −54° C. The post-firing photo of base pad and propellant bag of Runs 7 and 8 are shown in Figure 7(b).

(a)



(b)

Figure 7. Post-Firing Photographs of Bass Pad (Top) and Propellant Bag (Bottom). 28 g (1 oz) of Black Powder Used in Base Pad; (a) 203, (b) 123.

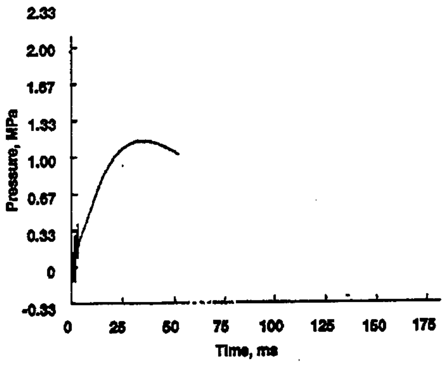


Figure 8. Pressure vs. Time for Run 6, Gauge 1. The 203 Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of 12° C.

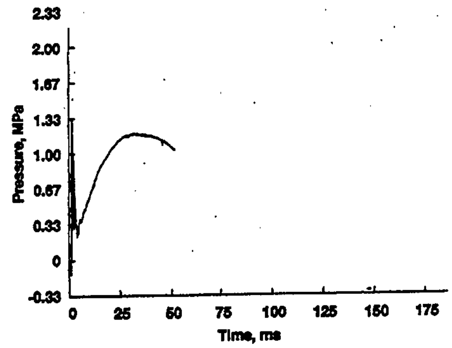


Figure 9. Pressure vs. Time for Run 6, Gauge 3. The 203 Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of 12° C.

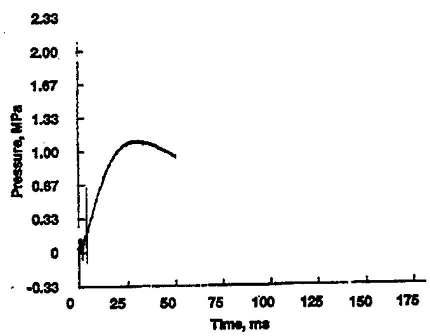


Figure 10. Pressure vs. Time for Run 7, Gauge 1. The 123 Interim Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of 13° C.

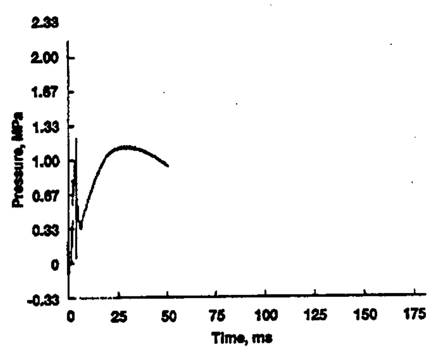


Figure 11. Pressure vs. Time for Run 7, Gauge 3.

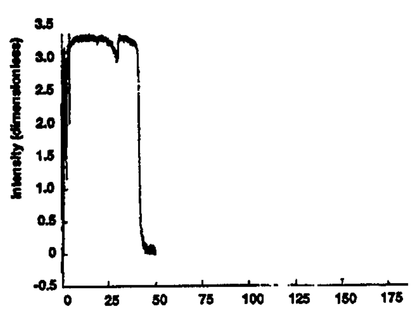


Figure 12. Intensity vs. Time for Diode 1, Run 7.

Again, no significant difference is seen due to the conditioning temperature. Close observation of Figure 7 shows, however, that there are some differences in cloth penetration between the 123 (viscose-rayon impregnated resin) and the 203 (polyester-viscose rayon). The 123 cloth (Figure 7[b]) is more subject to ignition damage than the 203 cloth. In fact, no penetration of the propellant bag is observed in Figure 7(a),whereas there are several holes in the propellant bag in Figure 7(b). Apparently, this difference in cloth had no substantial effect on the operation of the black powder, but it did inhibit the damaging effect of primer black powder output on the propellant bag. Pressure-time traces are shown in Figures 13 (Gauge 1) and 14 (Gauge 3).

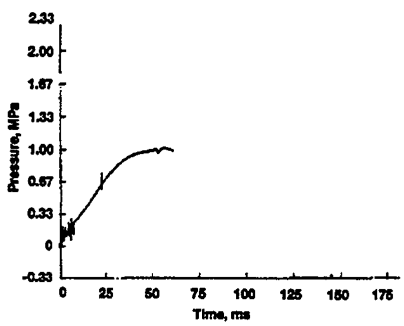


Figure 13. Pressure vs. Time for Run 8, Gauge 1. The 123 Interim Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of −54° C.

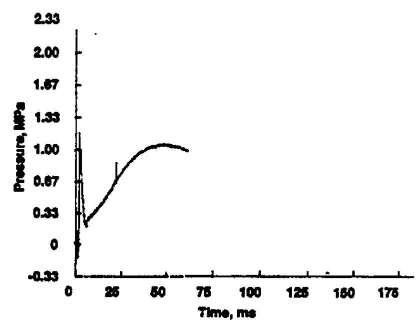


Figure 14. Pressure vs. Time for Run 8, Gauge 3. The 123 Interim Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of −54° C.

3.2 Question 2: Runs 9–12 and 17. Is ignition of the M30A1 propellant directly by the M82 primer possible, completely bypassing the igniter train? (Black powder was removed from the 203 charge igniter train.) The propellant was conditioned at −54° C.

3.2.1 Run 9. There was no evidence of propellant reaction of any kind in Run 9. The propellant grains were located in the propellant bag concentric with center core (Figure 4[b]).

3.2.2 Run 10. In this case, the propellant was placed in the base pad in direct alignment with the M82 primer output. A photograph of the base pad, propellant bag, and propellant is given in Figure 15. It can be seen that some of the graphite coating has been removed from the propellant

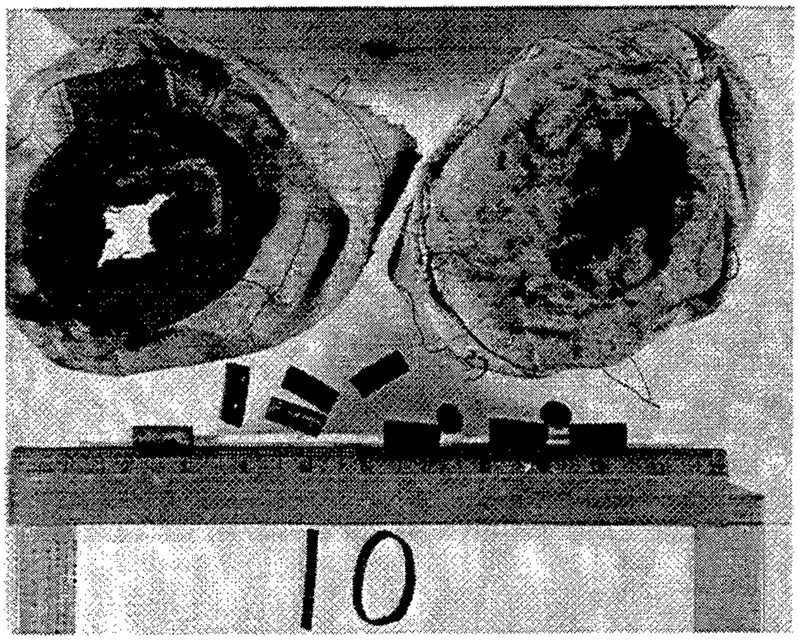


Figure 15. The 203 Base Pad (Left) and Propellant Bag (Right) for Run 10. Propellant Grains Placed in Base Pad. Some Graphite Coating Removed From the Grains by the M82 Output. No Evidence of Reaction.

grains, but there is no evidence of propellant reaction. It may also be noted that there was no penetration of the propellant bag.

3.2.3 Run 11. There is no evidence of propellant reaction. In this run and in Run 12, the propellant was placed in the propellant bag with 5 or 6 grains placed in the center core tube (a representative setup can be seen in Figure 16, Run 13. This propellant was backed up with inert propellant so that the primer output would not force the propellant down the central tube. It can be seen from Table 1 that the pressure measured by Gauge 3 from the M82 primer is larger for Runs 4–9 than for Runs 10, 11, or 12 (pressure traces not included in this report). This is due to the presence of the M30A1 and the inert propellant in the center core tube.

3.2.4 Run 12. The results for Run 12 are similar to Run 11.

3.2.5 Run 17. This run, like Runs 9–12, was an attempt at igniting the M30A1 propellant with the primer. This time, ambient conditions were used. No ignition was observed. One propellant

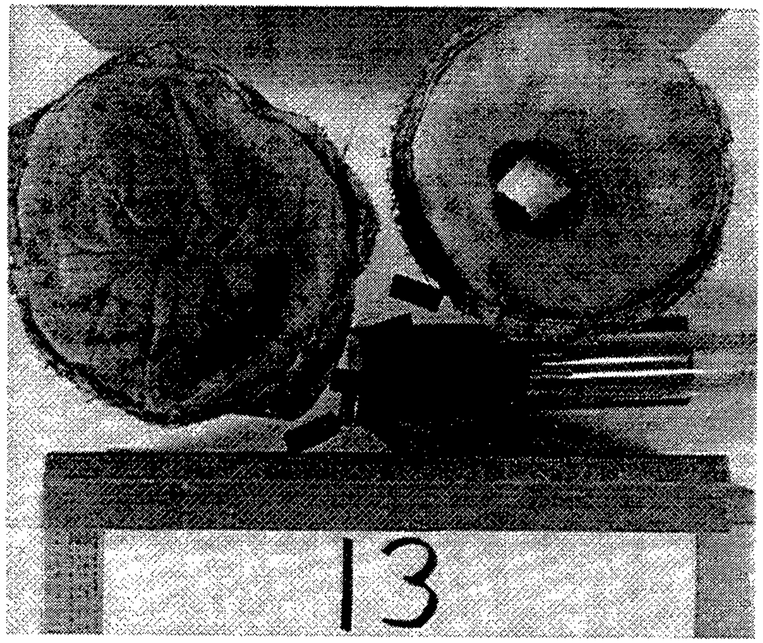


Figure 16. Post-Firing Photograph of Run 13: Propellant Bag (Left) and Flash Reducer (Right).

grain was broken, but there was no evidence of reaction. Table 1 shows that the primer pulse penetrates the propellant and base pad and reaches the back wall.

3.3 Question 3: Runs 13 and 20. Is it possible to ignite the ignition train or propellant with an inverted charge configuration? (A flash reducer was introduced between the charge and the M82 flash hole to simulate an inverted charge.)

3.3.1 Run 13. As is seen in Figure 16, there is no evidence for reaction of any kind. The output of the primer was absorbed in the flash reducer. It can be seen in Table 1 that the flash reducer prevents the primer output from reaching the end wall as Gauge 3 records a very small pressure rise.

3.3.2 Run 20. In this run, a simulated charge was constructed similar to an inverted charge. No ignition was observed.

3.4 Questions 4 and 5. These two questions are addressed in section 4.

3.5 Question 6: Runs 14, 19, and 21. What component of the ignition system is capable of yielding ignition delays on the order of 5–10 s?

3.5.1 Run 14. A M82 primer and only an NC tube were used. Only television recordings were made of this run. The ignition delay cannot be very accurately defined since the NC tube burns relatively slowly. Ignition delays were estimated from television recordings. Thus, it appears that the molded NC tube can give a long ignition delay of 5–10 s.

3.5.2 Run 19. In Runs 9–12 and 17, it was also shown that the M30Al propellant could not be ignited by the M82 primer. It was shown in this run (M82 primer, NC tube, and M30A1 propellant) that the molded NC tube could cause ignition of the M30Al propellant. Ignition time was taken from television recordings and was on the order of 5–10 s.

3.5.3 Run 21. The objective of this run was similar to that of 19, viz., to see if the molded NC tube could ignite the M30A1 propellant and cause an ignition delay of seconds. An important difference between this run and Run 19 is the difference in standoff distance between the base pad and primer spit hole. In Run 19, the standoff was approximately 1 cm, but, in this run, it was 5 cm. It should also be noted that, in Run 17, which had similar configurations with Run 21 (except for standoff distance and the use of the plastic tube instead of the NC tube), the primer penetrated both surfaces of the 203 base pad. (See Table 1 M82 - Gauge 3 for Run 17). However, with the 5-cm standoff of Run 21, the back of the base pad was not penetrated. (See Table 1 - M82 - Gauge 3, for Run 21). No ignition of the NC tube or propellant was observed.

3.6 Question 7: Runs 15, 26–29, 43, and 44. Can a missing base pad cause a hangfire?

3.7 Question 12: Runs 15, 26–29, 43, and 44. Does charge alignment affect ignition?

3.7.1 Run 15. This experiment was run as pictured in Figure 4(a) except that the base pad was emptied of black powder. The end of the snake was 8 cm from the base pad. Pressure-time trace is shown in Figure 17. It is seen that the delay is considerably longer than for the base pad alone, although far from hangfire conditions.

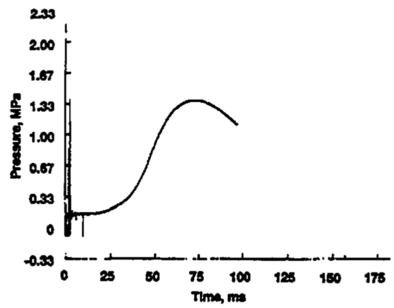


Figure 17. Pressure vs. Time for Run 15, Gauge 3. The 203 Base Pad (Empty) and Snake, 50 g of Black Powder and a Conditioning Temperature of −54° C.

3.7.2 Run 26. The ignition delay appeared normal for all runs except Runs 43 and 44. Reasons for this are given in section 3.7.6. In addition to the charge being 0.8 cm off center in Run 26, the snake was aligned such that it lay on the bottom of the NC tube. Peak pressures were not recorded due to saturation of amplifiers. Pressure-time traces for Gauges 1, 2, and 3 are seen in Figures 18, 19, and 20, respectively. A close examination of Gauge 1 and 3 show little pressure differentials and that there is a discontinuity in the curve at 0.28 MPa (40 psi) and 0.52 MPa (75 psi). Since there was no basepad these are probably due to erratic flamespreading in the snake.

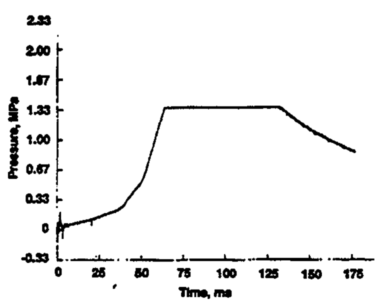


Figure 18. Pressure vs. Time for Run 26, Gauge 1. The 203 Base Pad (Empty) and Snake, 50 g of Black Powder and a Conditioning Temperature of −54° C.

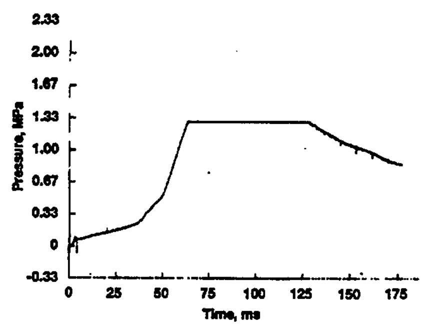


Figure 19. Pressure vs. Time for Run 26, Gauge 2.

3.7.3 Run 27. The inert propellant was eliminated from this run and from Run 28 and 29 because of the tendency to change the alignment of the charge. The inert propellant acts as a heat

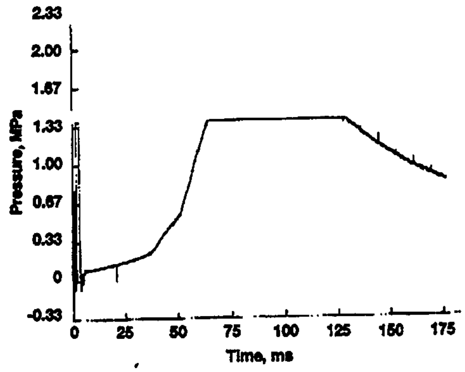


Figure 20. Pressure vs. Time for Run 26, Gauge 3.

sink for the igniter output and lowers the pressure that would ordinarily be achieved. As a consequence, the chamber pressure from the snake and NC tube ignition was increased and the acrylic tube ruptured before the peak pressure was reached. Consequently, peak pressures were not recorded. The chamber ruptured at about 2.2 MPa (350 psi). Again, a nonuniform flamespreading of the snake can be seen in the pressure-time curves (Figures 21–23) with discontimenities at 60 and 110 ms. Because of the misalignment, the M82 pulse was not observed (Table 1 and Figure 23). The ignition of the snake can also be seen on Diode 2 (Figure 24); a small emission at 60 ms followed by a strong emission at 110 ms. These coincide with the pressure measurements.

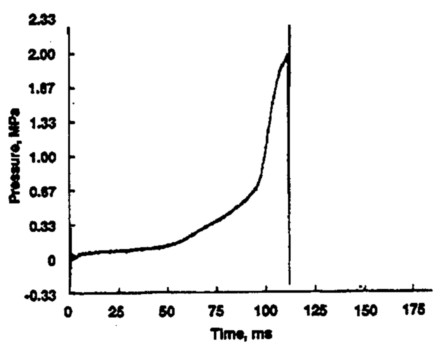


Figure 21. Pressure vs. Time for Run 27, Gauge 1. The 203 Base Pad (Empty) and Snake, 50 g of Black Powder and a Conditioning Temperature of −54° C.

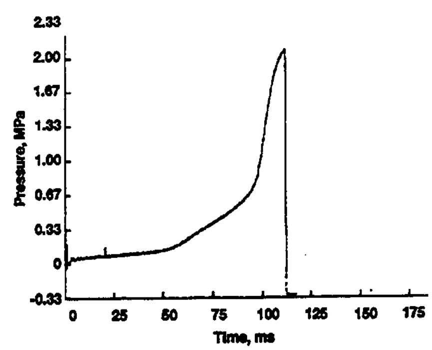


Figure 22. Pressure vs. Time for Run 27, Gauge 2.

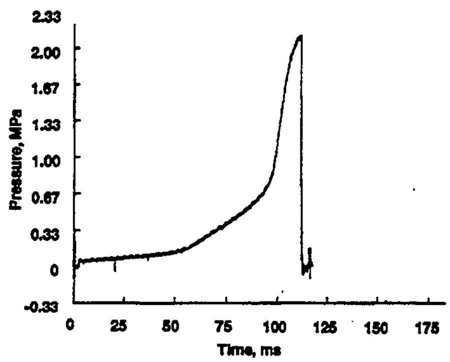


Figure 23. Pressure vs. Time for Run 27, Gauge 3.

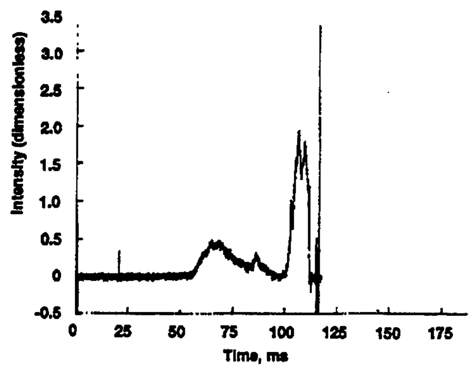


Figure 24. Intensity vs. Time for Run 27, Diode 2. The Sharp Increase in Intensity at 100 ms Corresponds to the Sharp Increase in Pressure, as Seen in Figures 21, 22, and 23.

3.7.4 Run 28. The snake was again placed at the bottom of the NC tube. The acrylic tube again ruptured, and peak pressures were lost. No significant delays were observed. Only Gauge 3 was used in Runs 28 and 29 because rupturing of the acrylic tube could cause damage to Gauges 1 and 2, which were mounted in the wall of the tube. Figure 25 shows a relatively long delay but a fairly smooth pressure-time trace. Figure 26 shows the pressure-time curve for Run 29.

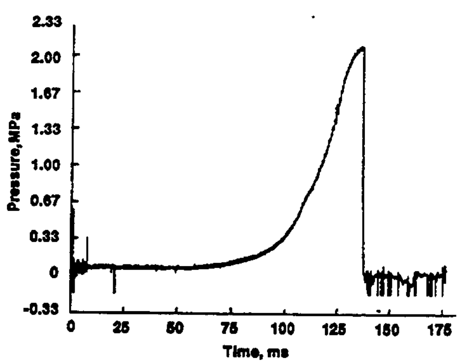


Figure 25. Pressure vs. Time for Run 28, Gauge 3. The 203 Base Pad (Empty) and Snake, 50 g of Black Powder and a Conditioning Temperature of -54° C.

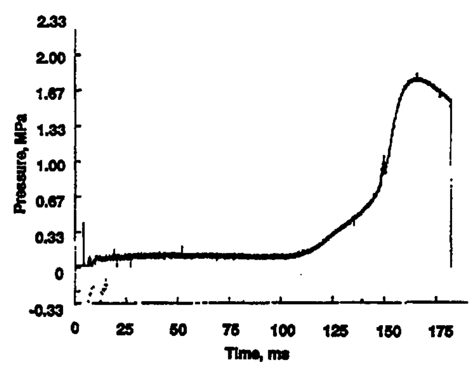


Figure 26. Pressure vs. Time for Run 29, Gauge 3. The 203 Base Pad (Empty) and Snake, 50 g of Black Powder and a Conditioning Temperature of -54° C.

3.7.5 Run 43. For this run and Run 44, a flash reducer was put on the far end of the charge (in front of Gauge 3, Figure 3[a]). The reason for this was because the pressure pulse from the M82 was reflected at the far end of the charge against the Gauge 3 wall. This could raise the gas temperature considerably and enhance the possibilities of ignition of the snake. (Runs 15 and 26–29 were carried out in this manner). The flash reducer would deflect the pressure pulse and inhibit this mechanism. For this run only, the NC tube ignited. The snake cloth was charred, but the black powder did not ignite (Figure 27). This test also demonstrated that the NC tube could itself ignite but that it would not necessarily ignite the black powder. Thus, it is conceivable that the M82 would ignite the end of the NC tube and this, in turn, could ignite the propellant without igniting the black powder snake.

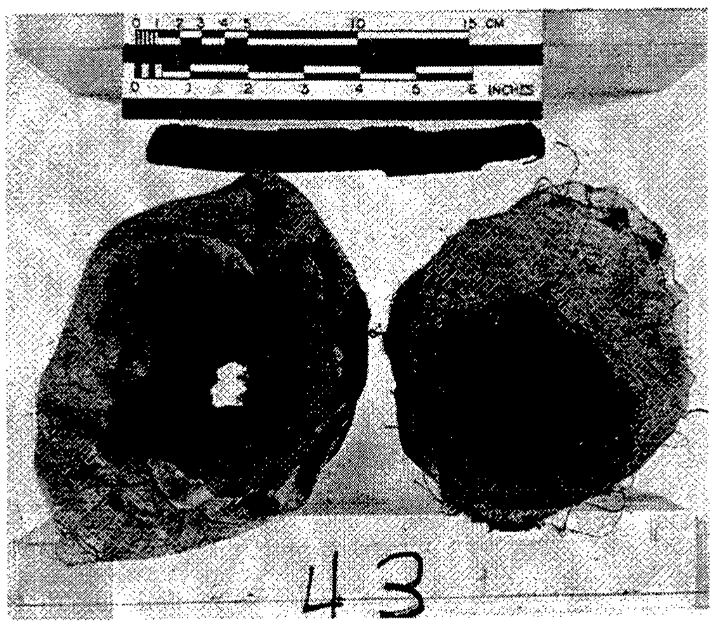


Figure 27. Post-Firing Photograph, Run 43. Base Pad (Left Empty), Snake (Top 0.05 kg [1.75 oz]). NC Tube Completely Burned Up. Snake Cloth Was Charred, but Black Powder Did Not Ignite.

3.7.6 Run 44. Neither the NC tube nor the snake ignited in this run, further showing the importance of the flash reducer as was described in Run 43.

3.8 Question 8: Run 16. How does moisture affect the ignition of the base pad?

For Run 16, the charge was warmed to room temperature and the base pad was soaked in a wet sponge for 5 min and replaced in environmental chamber at −54° C for 2 hr. The ignition delays were only slightly longer than those for Runs 4 and 5. The purpose of the procedure was to simulate the situation wherein the charge was allowed to rest on the wet ground, base pad down, for a period of 5 minutes and was then replaced in the environmental chamber. There were only very slight effects on the ignition delay. This subject was not pursued any further here because of extensive tests by Shulman et al. [6] at Picatinny Arsenal on the effect of moisture on the operation of the base pad. A somewhat smaller hole was produced in the base pad by the primer and black powder. It may also be noted from Table 1 that the M82 output did not penetrate the back of the base pad, as indicated by the low M82 pressure (0.07 MPa). It is possible that the ice, which was formed, prevented the penetration of the base pad.

3.9 Question 9: Run 18. Do 7.5 cm of empty snake cloth with a resulting 15-cm standoff affect the ignition of the snake?

For Run 18, due to a recording procedure error, no transducer records were obtained on this run. However, television recordings indicated that the ignition delay was under 1 s.

3.10 Question 10: Run 22. Will conditioning at dry-ice temperature (−78° C) significantly affect the performance of the base pad ignition?

For Run 22, the results can be seen in Table 1. There was no significant increase in ignition delay.

3.11 Question 11: Runs 24 and 25. Does the confinement of the charge within the chamber have an effect on the ignition of the snake by the base pad?

3.11.1 Run 24. This was a completely unconfined charge with no pressurization and no inert propellant. The only observations were with television. As was the case for previous runs of this kind (under a different experimental program), the base pad ignited in less than 1 s, followed by a delay of 15 s, after which the snake and molded NC tube ignited in a very rapid manner.

3.11.2 Run 25. Results for Run 25 were similar to Run 24.

3.12 Question 13: Runs 30–32 and 23. Is it possible to examine the pressure records from hangfire rounds 142 and 143 to determine if any or all of the igniter components functioned normally? What pressures should be expected from the igniter train, and, by examining the pressure records, can it be determined which elements functioned?

3.12.1 Run 30. It is very difficult to determine from a calculation what pressures should be expected from the igniter train under fully loaded conditions. This is because heat losses due to the propellant bed are difficult to estimate and to incorporate in a pressure calculation. Measurements of pressures in a full charge loaded with inert propellant may help answer this question. From Table 1 and Figures 28 and 29, it can be seen that there are two distinct events recorded. The first plateau pressure recorded on all three gauges is about 0.33 MPa and has a duration of 70 ms. This can, most likely, be attributed to ignition of the base pad. The second peak pressure occurred at 160 ms and was greater than 0.83 MPa. This pressure is due to ignition of the NC tube snake combination. The sudden drop in pressure observed in the records for this run was due to the rupturing of a sealing gasket. Consequently, peak pressures were not recorded. Figure 30 shows the intensity observed by Diode 2. The snake or base pad shows a small emission at 40 ms with a stronger emission at 140 ms.

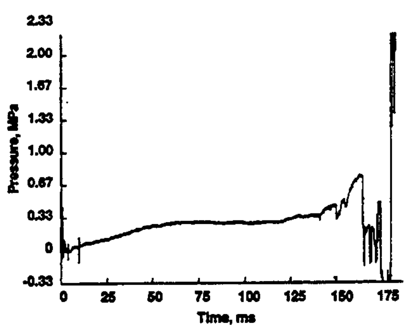


Figure 28. Pressure vs. Time for Run 30, Gauge 1. The 203 Base Pad (28 g) and Snake (112 g), Black Powder and a Conditioning Temperature of 15° C.

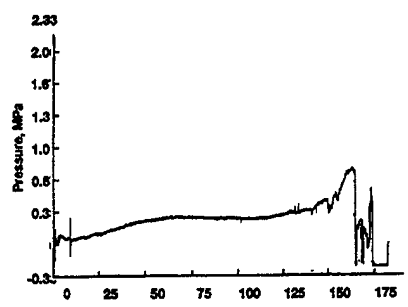


Figure 29. Pressure vs. Time for Run 30, Gauge 3.

3.12.2 Run 31. As seen from Table 1 and Figure 31, the pressure from the base pad was 0.34 MPa (50 psi) and, from the snake and remainder of the igniter, the peak pressure was 1.6 MPa (240 psi). The heat losses in this system, due to the inert propellant, are not necessarily the same as those using the M30A1 propellant. The ignition delay to maximum pressure for the base pad was 60 ms and, for the snake, was 165 ms, in good agreement with Run 30. The pressure-time trace for this run is shown in Figure 31.

3.12.3 Run 32. From Table 1 and Figures 32–34, base pad pressure observed was 0.34 MPa (50 psi) with a delay of 60 ms. The snake gave a peak pressure of 2.2 MPa (320 psi) with a delay of 160 ms. This is in good agreement with Runs 30 and 31, except for the snake peak pressure. A new sealing system was incorporated into Run 32, and the seal held until 1 s after peak pressure at which time it ruptured. Consequently, the peak pressures recorded in Run 32 are probably more representative of those that would be recorded under gun conditions if the propellant did not ignite. Pressure-time curves are shown in Figures 32, 33, and 34.

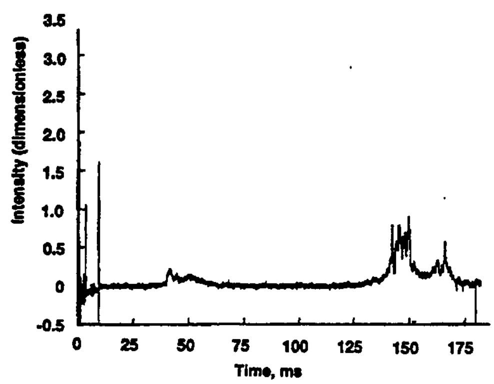


Figure 30. Intensity vs. Time for Diode 2, Run 30. The Snake Output Is Seen at 135 ms.

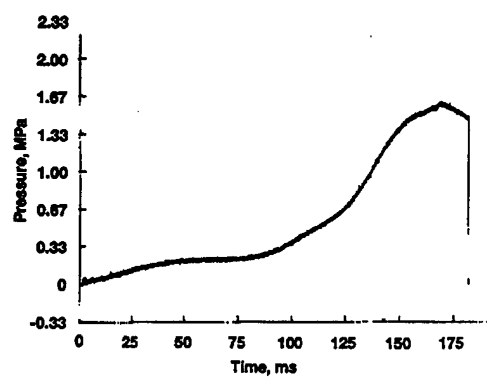


Figure 31. Pressure vs. Time for Run 31, Gauge 2. The 203 Base Pad (28 g) and Snake (112 g), Black Powder and a Conditioning Temperature of 15° C.

3.12.4 Run 23. What would the pressure-time profile be if there was no black powder in the base pad? This is shown in Table 1 and in Figures 35, 36, and 37.

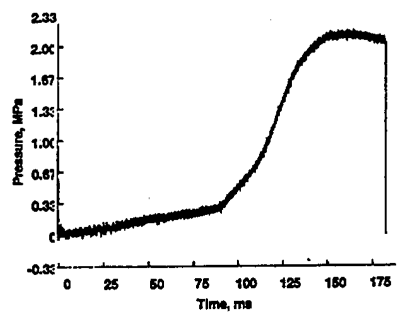


Figure 32. Pressure vs. Time for Run 32, Gauge 1. The 123 Interim Base Pad (28 g) and Snake (112 g), Black Powder and a Conditioning Temperature of 15° C.

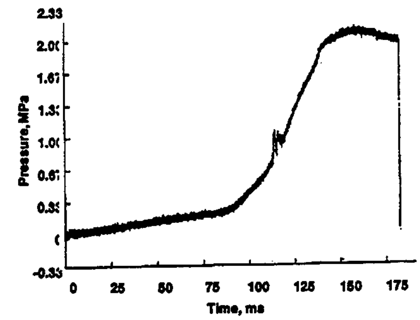


Figure 33. Pressure vs. Time for Run 32, Gauge 2.

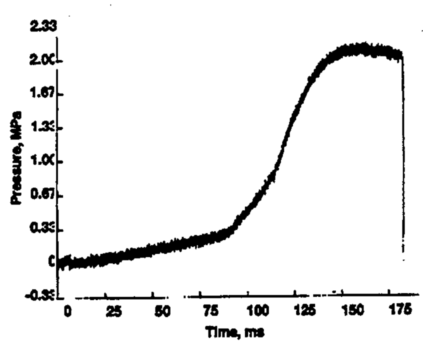


Figure 34. Pressure vs. Time for Run 32, Gauge 3.

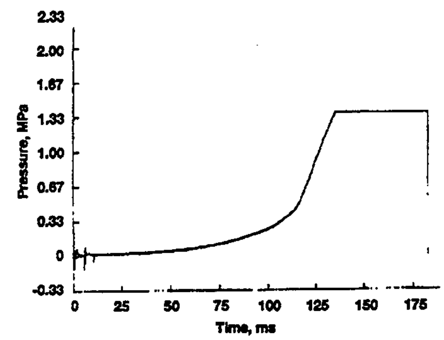


Figure 35. Pressure vs. Time for Run 23, Gauge 1. The 203 Base Pad (Empty) and Snake (112 g), Black Powder and a Conditioning Temperature of 15° C.

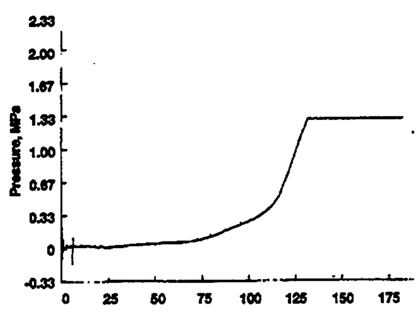


Figure 36. Pressure vs. Time for Run 23, Gauge 2.

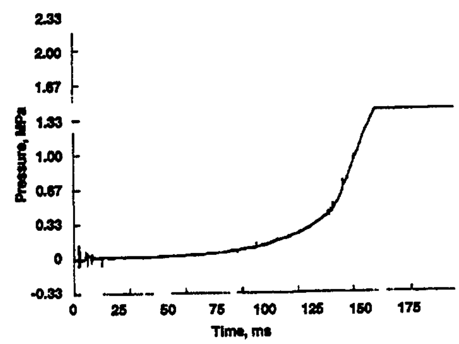


Figure 37. Pressure vs. Time for Run 23, Gauge 3.

3.13 Question 14: Runs 33–40. Can the 203 base pad ignite the M30Al propellant?

3.13.1 Run 33. The M30Al propellant grains were loaded in the propellant bag directly adjacent to the base pad. This was backed up by 12.5 cm of inert propellant. The final charge appeared as in Figure 4, with the exception that there was no snake and an aluminum tube was used in place of the plastic tube. Furthermore, in order to ensure that the propellant grains were properly located adjacent to the base pad, masking tape and a 0.25-mm Mylar disk were used. In an effort to cushion the effect of the metal tube on the base pad, a 2.5-cm section of molded NC tube was inserted into the end of the aluminum tube adjacent to the base pad. Results indicate the propellant is either not directly ignited by the base pad or is ignited with a long delay. It must be noted that this is for only one layer of the M30A1 propellant. A second comment that must be made concerns the presence of the paper Mylar barrier. This barrier will inhibit axial flow through the bed and will inhibit heat transfer from the igniter gases to the propellant. Consequently, Runs 33–38 must be repeated with the barrier removed to ensure valid results. This was done in Runs 39 and 40.

3.13.2 Run 34. This run was very similar to Run 33, with the exception that the 2.5 cm of molded NC tube was eliminated. In addition, the amount of propellant used was doubled in order to increase the chance for ignition. Again, the ignition delay for the propellant was long.

3.13.3 Run 35. All propellant grains recovered with no sign of reaction.

3.13.4 Run 36. Results are the same as for Run 35. Runs 33–35 indicate that at −54° C the base pad fails to ignite the propellant or results in a long ignition delay of the propellant.

3.13.5 Run 37. Numerous charges have been fired with the 123 charge without hangfire. Additionally, charges have been fired [2] with a base pad only under ambient conditions with no hangfires. The purpose of Runs 37 and 38 is to find out if the propellant can be ignited with the 123 base pad. Results were the same as for Run 35.

3.13.6 Run 38. It can be concluded from Runs 37 and 38 that the one layer of M30A1 propellant is difficult to ignite with a 28-g base pad of black powder. Since neither misfires nor hangfires were observed in other investigations [2] with only a base pad and propellant (−54° C), it must be concluded that either the propellant bed may ignite in a manner that is significantly different from the single layer or that the paper Mylar barrier inhibits ignition. As a consequence, one must be extremely cautious in drawing conclusions from Runs 33–36, concerning the failure of the base pad to ignite a propellant bed. Further experiments must be carried out on an entire bed of propellant rather than a single layer.

3.13.7 Run 39. The purpose of Runs 39 and 40 was to eliminate the flow barrier caused by the paper Mylar support used in Runs 33–38. Since the results of Runs 39 and 40 were substantially the same as Runs 33–38, then it can be assumed that the barrier was not significant in the propellant ignition of Runs 33–38.

3.13.8 Run 40. Again, it may be concluded that, for one layer of propellant, long ignition delays are encountered for the propellant when only the base pad is used in the igniter train.

3.14 Question 15: Runs 41 and 42. Is it possible for the black powder in the base pad to have moved from the penetration area of the M82 primer and, consequently, have no ignition?

3.14.1 Run 41. Black powder was sifted out of one segment of the base pad, and the primer fired into that empty segment of the base pad. Ignition delay was normal for the base pad. The purpose of this run and Run 42 was to determine if the black powder could have sifted into one segment of the base pad with the primer firing into the empty segment.

3.14.2 Run 42. Results of this test were essentially the same as Run 41. Figures 38 and 39 show the pressure-time curves. Figure 40 shows the signal from Diode 1. The light emission from the M82 primer can be clearly observed (1.5 ms) followed by light emission from the base pad (8 ms). This is also seen in Figure 41 for Diode 2. The pressure pulse transit time from one end of the chamber to the other can be found from Figure 42 (2.8 ms − 1.5 ms = 1.3 ms).

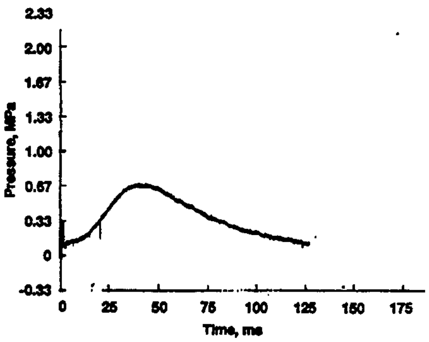


Figure 38. Pressure vs. Time for Run 42, Gauge 1. The 203 Base Pad With 28 g (1 oz) of Black Powder and a Conditioning Temperature of -54° C.

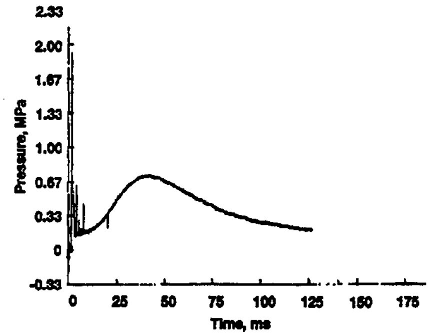


Figure 39. Pressure vs. Time for Run 42, Gauge 3.

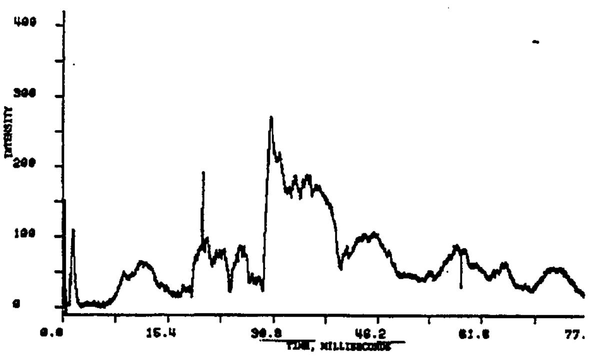


Figure 40. Intensity vs. Time for Diode 1, Run 42.

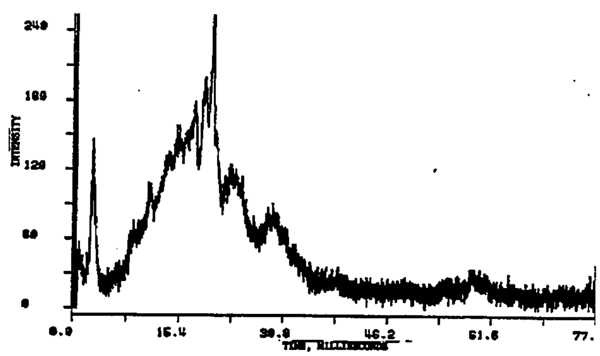
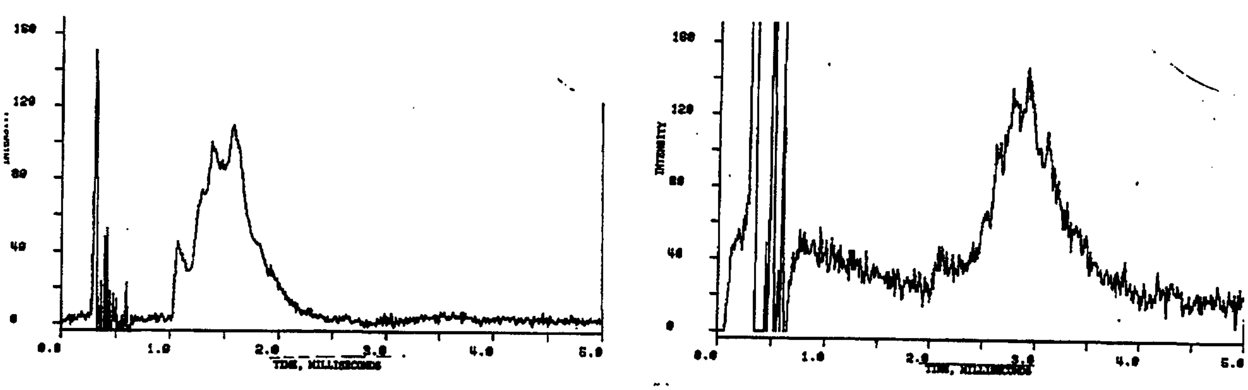


Figure 41. Intensity vs. Time for Diode 2, Run 42.



(a)

(b)

Figure 42. Intensity vs. Time for (a) Diode 1, Run 42 (Peak Intensity for M82 Occurs at 1.5 ms) and (b) Diode 2, Run 42 (Peak Intensity for M82 Occurs at 2.8 ms). The Difference in Time Is Due to Transit Time of M82 Pulse Down the Center Core Tube.

4. Conclusions

In this section, each question stated in the section 1 is addressed and answered based on analysis of the test results.

4.1 Question 1. Is there a difference in the base pad performance between the 203 and the 123 due to the change in material?

In referring to Figure 43, it can be seen that there is a substantial difference in cloth porosity between the cloth used in the 123 charge and the cloth used in the 203 charge. Only the inner base pad cloth is shown. Figure 7 shows the residue of the base pad (top) and propellant bag (bottom) after firing of an abbreviated charge, as in Figure 4. The base pad contained 28 g (1 oz) of black powder, there was no snake, and an inert central core tube was used.

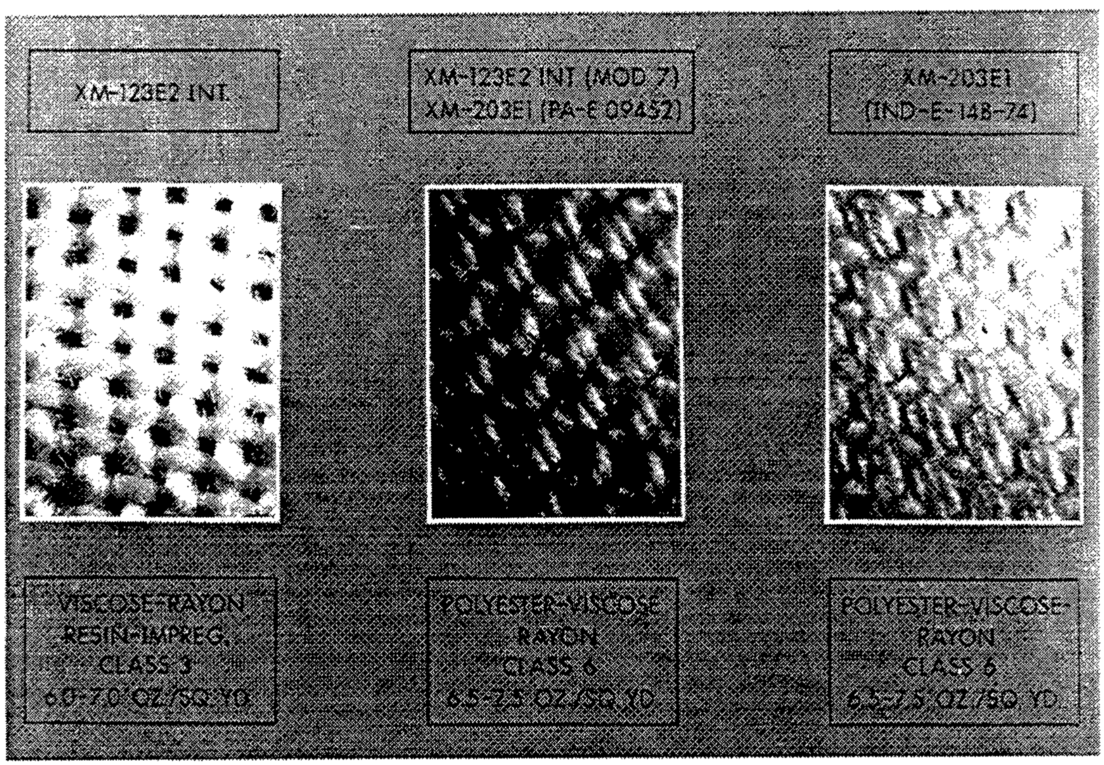


Figure 43. Inner Lining of Base Pad Cloths Used in 123 Interim (Left) and 203 (Right). The XM123E2 Interim (Mod 7) Cloth Is Not Discussed in This Report.

It is seen that the penetration of and damage to the propellant bag is substantially greater for the 123 system than the 203 system. Apparently, the heavier cloth with a finer weave inhibits the transfer of energy into the propellant bed. The pressure-time curves of two different base pads (Figures 5 and 13) do not show any substantial difference, which indicates that the overall energy output is not altered and only the transfer of energy to the propellant is affected by the cloth.

4.2 Question 2. Is ignition of the M30A1 propellant directly by the M82 primer possible, completely bypassing the igniter train?

A number of rounds were fired in which the M82 output interacted directly with the M30Al propellant under loading conditions similar to the cannon. In no case was the propellant directly ignited by the M82 primer. The only result was that some of the graphite coating was removed from the propellant.

4.3 Question 3. Is it possible to ignite the ignition train or propellant with an inverted charge configuration?

All charges fired in an inverted mode resulted in misfires only. The output from the M82 primer was absorbed by the flash reducer. As a consequence, it is unlikely that the hangfire was caused by an inverted charge.

4.4 Question 4. Was the M82 primer output altered in some way so as to be ineffective in igniting the black powder?

Tests were carried out at Picatinny Arsenal [4] to determine if there were any malfunction in the M82 primer. It was found that the M82 primers from the same lot as the malfunction behaved in a normal manner.

4.5 Question 5. Was the black powder used in the XM203E1 charge (Lot CIL 7–3) ballistically defective?

Pressure-time curves for the black powder used in the 203 and 123 charges did not show any substantial differences. Closed-bomb tests at Picatinny Arsenal also showed no significant differences.

4.6 Question 6. What component of the system is capable of yielding ignition delays from 5–10 s?

Experiments were carried out in which the charge (Figure 3) did not contain any black powder but had the 35.5-cm NC tube and some M30A1 propellant located in the inert bed. It was observed that the NC tube was ignited in a fizz mode by the M82 primer and, about 5–10 s later, the propellant ignited. A question that must now be answered is, "If the NC tube ignites in a fizz mode, will it first ignite the black powder snake or the M30Al propellant?" If it ignites the snake, then such an ignition mode might lead to a hangfire but not necessarily to a catastrophic pressure history since the ignition of the snake prior to the propellant would lead to relatively uniform ignition of the propellant bed. If, on the other hand, the propellant ignited before the snake, then localized ignition might occur, leading to generation of catastrophic pressure waves. An experiment was conducted at Picatinny Arsenal [6] in which the NC tube was ignited by a hot nichrome wire instead of the M82 primer or base pad. With this type of ignition, it was found that 2 out of 3 snakes with 203 cloth did not ignite and 3 out of 15 snakes with 123 cloth did not ignite. This would indicate that, in the cases where the snakes did not ignite, the NC tubes burned in a fizz mode and did not transmit sufficient heat to ignite the black powder in the snake. This was confirmed by a test using an M82 primer, empty base pad, snake with 0.05 kg (1 3/4 oz) of black powder, and a 35.5-cm NC tube (Run 43). The NC tube ignited and burned but left behind the unignited snake, as seen in Figure 27. It was concluded that it is possible to ignite the NC tube in a fizz burn mode, which subsequently bursts into full flame (television records) and causes a delayed ignition of the propellant, completely bypassing the black powder snake.

4.7 Question 7. Can a missing base pad cause a hangfire?

Tests were conducted with an empty base pad but included the snake with black powder and NC tube. Hangfires were observed under these conditions when the charge was misaligned with respect to the primer output by 1.3 cm (as is the case in the howitzer) and when care was taken to avoid the M82 primer output being reflected off of the back wall of the chamber and passing over the snake. Consequently, it was concluded that an empty base pad with the charge misaligned could cause a hangfire. However, the absence of base pads on two successive charges was considered to have a low probability and, therefore, unlikely to be the cause of the two hangfires.

4.8 Question 8. How does moisture affect the ignition of the base pad?

Tests conducted in which charges were subjected to high humidity conditions did not demonstrate any hangfires. During tests at Picatinny Arsenal, under extreme conditions of soaking the base pad in water, a misfire was encountered; however, no hangfires were observed. Consequently, moisture was not considered to be a significant factor in the hangfire incident.

4.9 Question 9. Do 7.5 cm of empty snake cloth with a resulting 15-cm standoff affect the ignition of the snake?

In answer to Question 9, where there was a possibility of a longer snake to base pad standoff, for the short snake configuration, 23.5 cm (9 1/4 in), and a well-aligned center core, a 15-cm (6 in) standoff between the base pad and the black powder in the snake does not substantially affect the ignition delay.

4.10 Question 10. Will conditioning at dry-ice temperature (−78° C) significantly affect the performance of the base pad ignition?

Very low temperatures of −78° C (−109° F) do not materially affect the ignition of the base pad, as pressure-time traces indicate normal behavior.

4.11 Question 11. Does the confinement of the charge within the chamber have an effect on the ignition of the snake by the base pad?

The unconfined igniter train demonstrated hangfire conditions. This was true even for 123 charges. This indicates that pressurization and the confinement of the flow of the igniter gases is important for igniting the snake in a rapid manner. Other tests at Picatinny Arsenal [4] showed the importance of pressurization on the ignition of the propellant.

4.12 Question 12. Does the charge alignment affect ignition?

Tests conducted on charges containing snakes but with empty base pads, in which the axis of the charge was carefully aligned with respect to the primer hole, did not show any hangfires. However, when the charges were misaligned (as they are in the howitzer), hangfires were encountered. Hence, it is concluded that alignment can be a factor in producing hangfires.

4.13 Question 13. Is it possible to examine the pressure records from hangfire rounds 142 and 143 to determine if any or all of the igniter components functioned normally?

What pressures should be expected from the igniter train, and, by examining the pressure records, can it be determined which elements functioned? In answer to Question 13, full-length charges (74 cm) containing inert propellant and a full igniter train were fired in a 79-cm chamber (17-cm diameter) in order to record the pressure histories. One of these is shown in Figure 31. It is seen that the pressure generated by the base pad is approximately 0.35 MPa (50 psi) and that due to the snake and NC tube is 1.73 to 2.14 MPa (250 to 310 psi). A detailed examination of data from Rounds 142 and 143 from the malfunction (Figure 2) show that these low pressures are obscured in electronics noise and cannot be retrieved.

4.14 Question 14. Can the 203 base pad ignite the M30A1 propellant?

In answer to Question 14, as to whether the base pad alone can ignite the propellant, experiments were carried out in which M30Al grains were placed in the propellant bag directly adjacent to the base pad containing 0.028 kg (1 oz) of black powder, as in Figure 3(a). The M82 primer successfully ignited the base pad, but hangfires and misfires were encountered with respect to the propellant. These results must be treated cautiously since there was only one layer of propellant and a full propellant bed may have different ignition characteristics.

4.15 Question 15. Is it possible for the black powder in the base pad to have moved from the penetration area of the M82 primer and, consequently, have no ignition?

For the limited testing that was done here, the base pad will ignite even when the black powder is sifted out of the penetration area of the M82 primer output.

5. Summary

5.1 Hangfire Event. The answers given in the previous section point out what conditions probably did not cause the 20 December 1974 hangfire incident, and they point to a number of factors that may have contributed to the hangfire. With these results in mind, a likely sequence of events that may have resulted in the hangfire event follows. The M82 primer ignited normally with an output adequate to ignite the black powder base pad. The base pad also ignited normally but did not ignite either the black powder snake or the M30A1 propellant; rather, it caused the NC tube to ignite in a fizz-burn mode. The NC tube ignited the M30Al propellant locally after a delay of some seconds. This localized ignition caused generation of pressure waves, which led to the malfunction. Factors contributing to the malfunction were: (1) the misalignment between the primer output and center core of the charge; (2) a low temperature $-54°$ C ($-65°$ F); (3) the viscose-rayon Class 6 cloth in the 203 igniter system, which inhibited transfer of energy from the base pad to the snake or the propellant bed.

An alternative, though less likely, explanation is that the entire ignition train ignited normally but did not ignite the propellant bed due to a low pressure caused by leakage in the gun chamber. This poor energy transfer to the propellant bed aggravated by the low temperature and the heavier cloth used in the 203 igniter system. This hypothesis was based on a series of experiments using the igniter train of base pad (28 g, 1 oz of black powder) and a few grains of M30Al propellant and NC tube in the glass bead bed fired in a 91-cm simulator. A total of 15 rounds was fired, with various size holes in the end plate. Although some instances were encountered in which the propellant did not ignite, the base pad, snake, and NC tube ignited in each case. The question of the ignition of the snake could be answered from the firings performed in the Picatinny Arsenal interrupted burner cannon [8]. This device is essentially the XM198 chamber (with barrel removed). A blowout disk is used in place of the projectile. Full charges were fired in this device, and a substantial number of hangfires were encountered with the 203 charge.

In addition to the causes related to the 155-mm malfunction, certain other conclusions have come from this study and the other works [5, 6].

(1) Final pressure achieved in the chamber due to the igniter is very important for good propellant ignition.

(2) The functioning of black powder is relatively insensitive to moderate conditions of moisture and low temperature, and did not differ significantly for different lots.

(3) If, indeed, the base pad fails to ignite the snake, then gas flow dynamics are extremely important for energy transfer in black powder ignition and will have to be carefully examined in each instance.

(4) Black powder and the triple-base propellant show quite different ignition characteristics depending on ignition heating rates.

(5) The M82 primer is very well suited to igniting black powder even under a variety of aggravated conditions, provided the M82 output has the chance to interact with the black powder.

5.2 General Conclusions. The stated purpose of this work was to arrive at the principal causes of the 155-mm howitzer malfunctions, and these have been previously outlined. However, in addition to this, some general qualitative features can be outlined here on the functioning of various components of the system.

(1) The M82 pulse width at the end wall is approximately 2–3 ms.

(2) The transit time for the M82 pulse to go from the spit hole to the end wall is approximately 1.3 ms, leading to a velocity of 350 m/s.

(3) The light pulse observed by Diode 2 coincides in time with the pressure detected by Gauge 3 (Figures 39–42). If the diode observed the M82 pulse as it penetrates the base pad, the signal should occur prior to the Gauge 3 pressure pulse. Since it is, instead, coincident, this implies that the stagnation at the back wall causes an increase in gas temperature and luminosity.

(4) The ignition of the snake alone is significantly affected by alignment with respect to the M82. This is clearly evident in Table 1 for Runs 15 and 26–29. An increasing misalignment results in an increasing ignition delay.

(5) The ignition delay of the base pad can be detected by the diodes and is given in Table 1.

(6) From the pressure-time curves for the full charges (Figures 31 and 32), it is seen that the maximum pressure experienced by the charge due to the igniter is 2.41 MPa (350 psi). The base pad alone gives a pressure of no more than 0.34 MPa (50 psi).

(7) The flamespreading in the snake is not uniform and can be seen in the pressure-time curves (Figures 18, 21, 25, and 26) as an irregularity in dP/dt.

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13. ABSTRACT *(Maximum 200 words)*

On 20 December 1974, two hangfires occurred in a developmental 155-mm howitzer at Aberdeen Proving Ground (APG), MD. The second hangfire was accompanied by a rupturing of the howitzer breech. As a result of this, a laboratory study was initiated to uncover possible causes leading to the malfunction. The study involved testing of various components of the igniter train singly and in various combinations under a variety of environmental conditions.

The sequence of events leading to the hangfires was as follows: the primer ignited the base pad, which did not ignite the propellant nor the black powder containing central core "snake." The NC tube ignited to a fizz burn after a period of seconds and eventually ignited the propellant that caused the hangfires. The ignition occurred in a localized region near the breech, leading to the pressure waves of extreme magnitude. Subsequent high pressures that ruptured the breech may have come about because of propellant grain fracture due to pressure wave induced acceleration against the projectile. The difference between the apparently reliable operation of the XM123E2 interim propellant charge and the charge (XM203E1) used in the hangfires and in this study was due to the change in igniter train cloths. This was confirmed by post-firing analysis of cloth residues, visual differences in cloth density, and full-scale blowout cannon results.

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